

BASEBAND PULSE SHAPING TECHNIQUES FOR NONLINEARLY AMPLIFIED $\pi/4$ -QPSK AND QAM SYSTEMS

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ABSTRACT

A new generation of multi-state $\pi/4$ -shifted QPSK and of Superposed Quadrature-Amplitude-Modulated (SQAM) modulators-coherent demodulators (modems) and of Continuous Phase Modulated (CPM)-Gaussian Premodulation Filtered Minimum-Shift-Keying (MGMSK) systems is proposed and studied. These modems will lead to bandwidth and power efficient satellite communications systems designs. As an illustrative application, a new baseband processing technique $\pi/4$ -Controlled Transition PSK ($\pi/4$ -CTPSK) is described. To develop a cost and power efficient design strategy, we assume that nonlinear, fully saturated high power amplifiers (HPA) are utilized in the satellite earth station transmitter and in the satellite transponder. Modem structures which could lead to Application-Specific-Integrated-Circuit (ASIC) satellite on-board processing "universal" modem applications are also considered.

Multistate GMSK (i.e., MGMSK) signal generation methods by means of two or more RF combined nonlinearly amplified SQAM modems and by one multistate (in-phase and quadrature-baseband premodulation filtered-superposed) SQAM architecture and one RF nonlinear amplifier are studied. During the SQAM modem development phase we investigate the potential system advantages of the $\pi/4$ -shifted logic (such as used in the U.S. digital cellular standard $\pi/4$ -DQPSK). The bandwidth efficiency of the proposed multistate GMSK and baseband filtered PAM-FM modulator (a new class in the CPM family) will be significantly higher than that of conventional G-MSK systems. To optimize the practical $P_e = f(E_b/N_0)$ performance we consider improved coherent demodulation MGMSK structures such as "deviated-frequency locking" coherent demodulators.

For relative low bit rate SATCOM applications, e.g., bit rates less than 300 kb/s, phase noise tracking-cancellation (for fixed site earth station) and phase noise cancellation as well as Doppler compensation (for satellite to mobile earth station) applications may be required. We study "digital channel sounding" methods which could cancel the phase noise-caused degradations of CPM and GMSK modems. The spectral-bandwidth efficiency of the proposed new class of modems will be in the 2b/s/Hz to 5b/s/Hz range with an anticipated out-of-band adjacent channel interference (ACI) in the ACI > -30dB to -40dB range. Hardware design and experimental optimization of a coherent multistate GMSK-SQAM structure will be initiated during the 1991-92 academic year. In this paper some of our preliminary research results, as of August 1991, are highlighted.

1. $\pi/4$ -QPSK AND GMSK MODEMS

Modems suitable for digital satellite communications systems and for land mobile applications should satisfy at least the following requirements:

- A power efficient nonlinear amplifier may be used without introducing significant ACI, thus enabling efficient spectral utilization.
- A detection scheme able to achieve fast synchronization (including coherent and differential/discriminator detection) and good BER performance should be used.

In the search for modulation schemes which satisfy these requirements, numerous authors studied the “ $\pi/4$ -shifted QPSK systems,” see Figure 1 through Figure 4. In this scheme, envelope fluctuations are significantly reduced compared to QPSK [Ref. 1]. Also, noncoherent detection schemes may be successfully applied to $\pi/4$ -QPSK modulated signals. It has been shown that this modulation scheme achieves **double the spectral efficiency** of comparable constant envelope modulation schemes such as Gaussian Filtered MSK or GMSK. Note that GMSK has been adopted as the standard modulation format for the European DECT and GSM personal communications/cellular systems [Ref. 1; 4]. Due to the attractive features of $\pi/4$ -QPSK, it has been chosen as the standard modulation scheme for the planned U.S. digital mobile radio system.

2. NEW IMPROVED MODEMS - DEVELOPED AT UC DAVIS

Experimental measurements at UC Davis and numerous other research laboratories indicate that in fully saturated, nonlinearly amplified systems $\pi/4$ -QPSK has a significant spectral restoration, see Figure 5 [Ref. 1; 2; 3; 5]. For this reason we initiated a research program with an objective to maintain the attractive properties of $\pi/4$ -QPSK and also to reduce the spectral spreading. In Figure 6 a new reduced spectrum $\pi/4$ -QPSK modem, based on the SQAM concept is illustrated [Ref. 2]. In Figure 7 a particular baseband processed waveshape for CTPSK (controlled transition PSK) is illustrated [Ref. 3].

In an effort to reduce the envelope fluctuation of $\pi/4$ -QPSK, a sinusoidal shaping scheme was introduced by Katoh-Feher in [Ref. 2]. This scheme sinusoidally shapes the phase transitions to reduce envelope fluctuations. The spectral advantages are shown in Figure 6. In our CTPSK scheme, in addition to a shaping technique, we also offset data transitions in the I and Q channels to further smooth the resulting phase transitions [Ref. 3], see Figure 7. The NLA (nonlinearly amplified) spectral advantages of our $\pi/4$ -CTPSK, as compared to conventional $\pi/4$ -QPSK are shown in Figure 8. An intuitive indication for this spectral reduction, after NLA, is the reduced envelope constellation diagram of the $\pi/4$ -CTPSK signal, shown in Figure 9.

In Figure 10, we illustrate the NLA concept extended for SQAM and $\pi/4$ -CTPSK systems to 64-QAM configurations. In our previous research we demonstrated that for conventional SQAM the $\text{BER} = f(E_b/N_0)$ results are close to theoretical performance, even in saturated NLA systems [Ref. 4], see Figure 13 and [Ref. 4 and 7]. For phase noise and Doppler shift compensation of relatively low bit rate mobile systems, we initiated the study of digital and analog pilot aided phase noise compensated modems [Ref. 1], see Figure 12.

For ASIC (Application-Specific-Integrated-Circuit) satellite on-board processing “universal” modem applications we are also studying the CPM-GMSK type of structures, illustrated in Figure 11. The resemblance between the GMSK and the QAM (SQAM) and QPSK transmitters/receivers could lead to universal ASIC implementations.

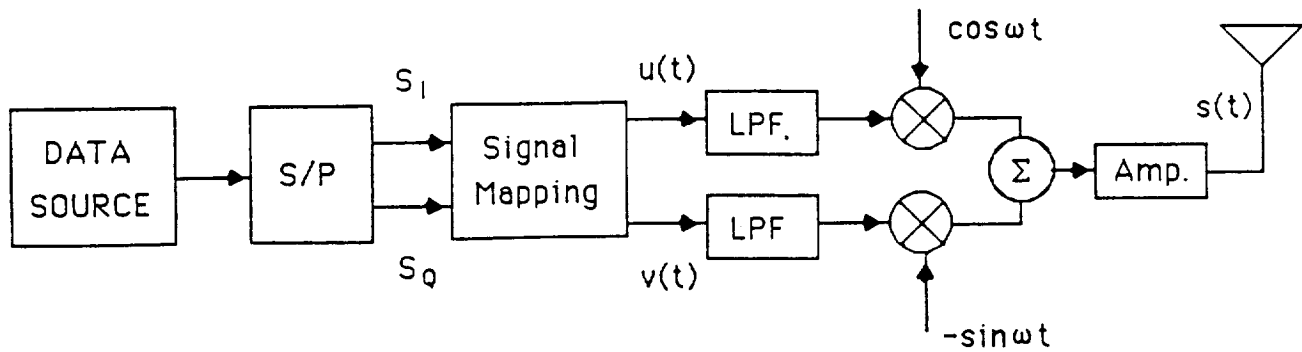


Figure 1. Block diagram of the transmitter of the $\pi/4$ -QPSK modem.

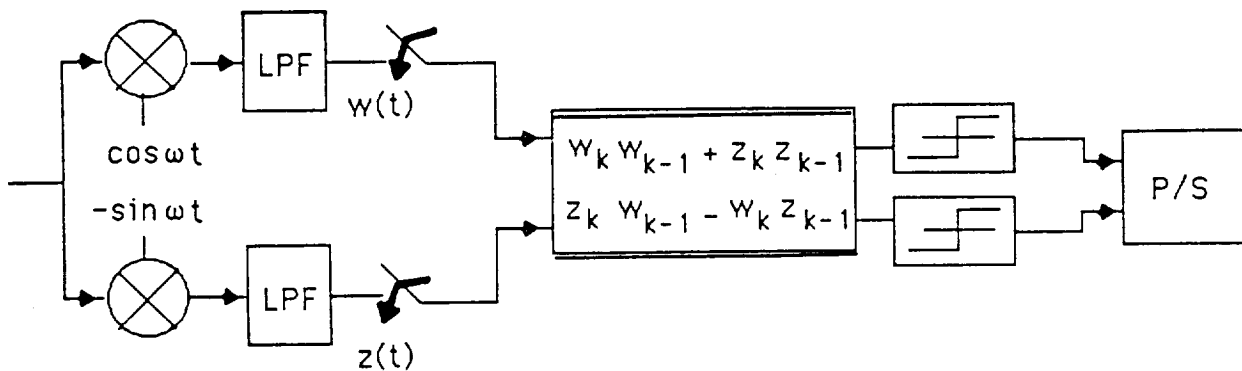


Figure 2. Block diagram of a $\pi/4$ -QPSK coherent demodulator.

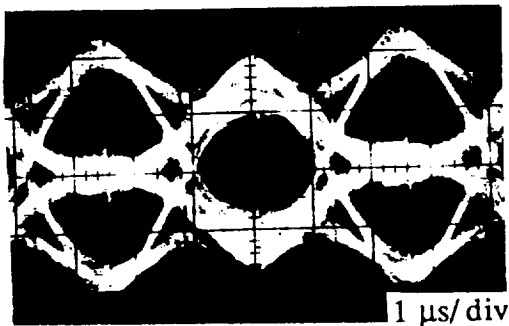


Figure 3. The "five-level" eye-diagram of coherent demodulated $\pi/4$ -QPSK signals. At every other sampling instant the signals are two level. In between, the signals are three-level. Only the in-phase channel is shown. The bit rate used in this experimental setup is 800 kb/s.

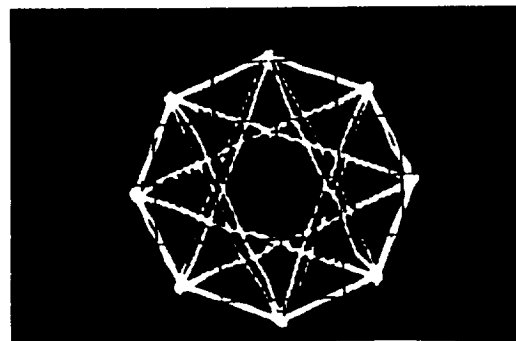


Figure 4. Constellation of the $\pi/4$ -QPSK signal. In this hardware experiment, sine wave shaping $\pi/4$ -QPSK (SP-QPSK) is used.

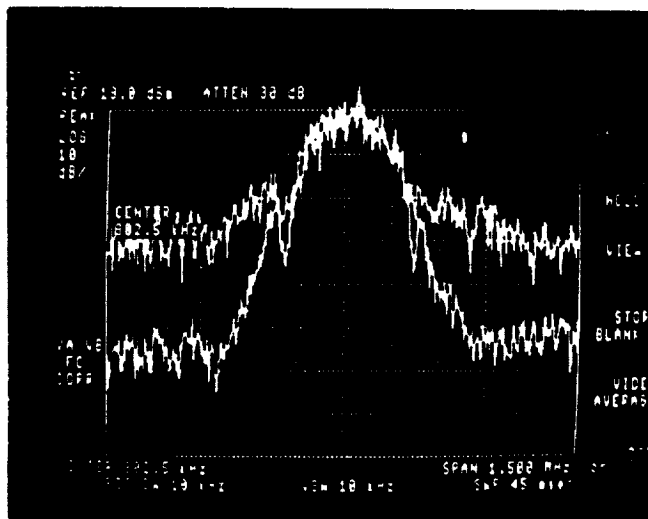


Figure 5. Experimental measurement results of the power spectral density of non-linearly amplified band limited $\pi/4$ -QPSK. $f_b = 400$ kb/s, $f_c = 1.18$ MHz, Horizontal scale: 200 kHz/div, Vertical scale: 10 dB/div.

- (a) Upper trace: saturated amplifier.
- (b) Lower trace: amplifier input back-off 2dB measured on a prototype modem designed at UC Davis.

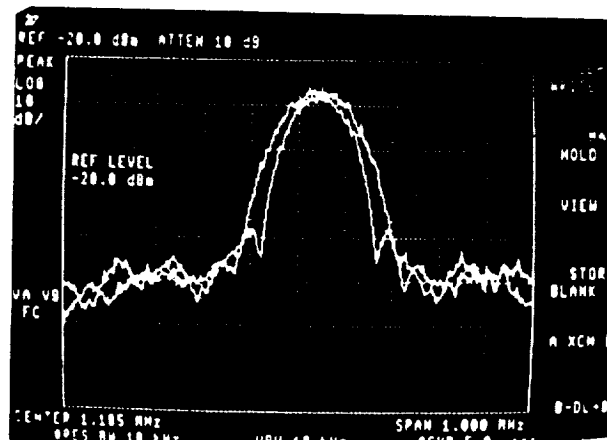


Figure 6. A new generation of improved performance $\pi/4$ -QPSK modems developed at UC Davis has a reduced out-of-band spectrum in nonlinearly amplified (power efficient) radio system applications. In the illustrated spectral measurement we use an $f_b = 250$ kb/s rate. These " $\pi/4$ -QPSK" (upper trace) and "SQAM" modems (lower trace) are described in [2; 14; 19; 21; and 24]. Horizontal scale: 100 kHz/div; vertical: 10 dB/div.

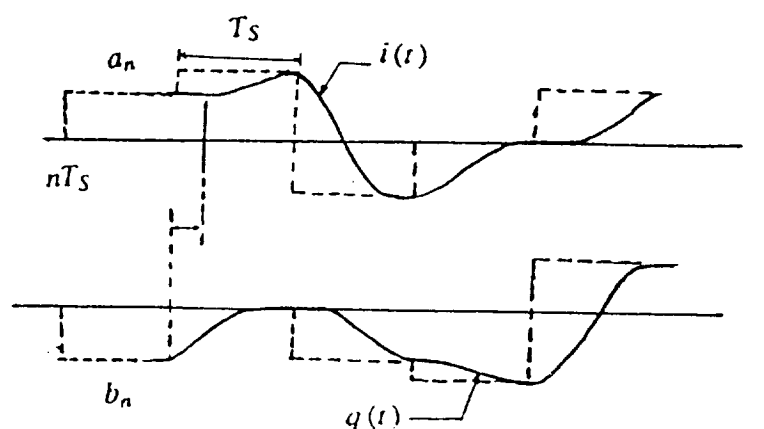


Figure 7. An illustration of $\pi/4$ - CTPSK processing.

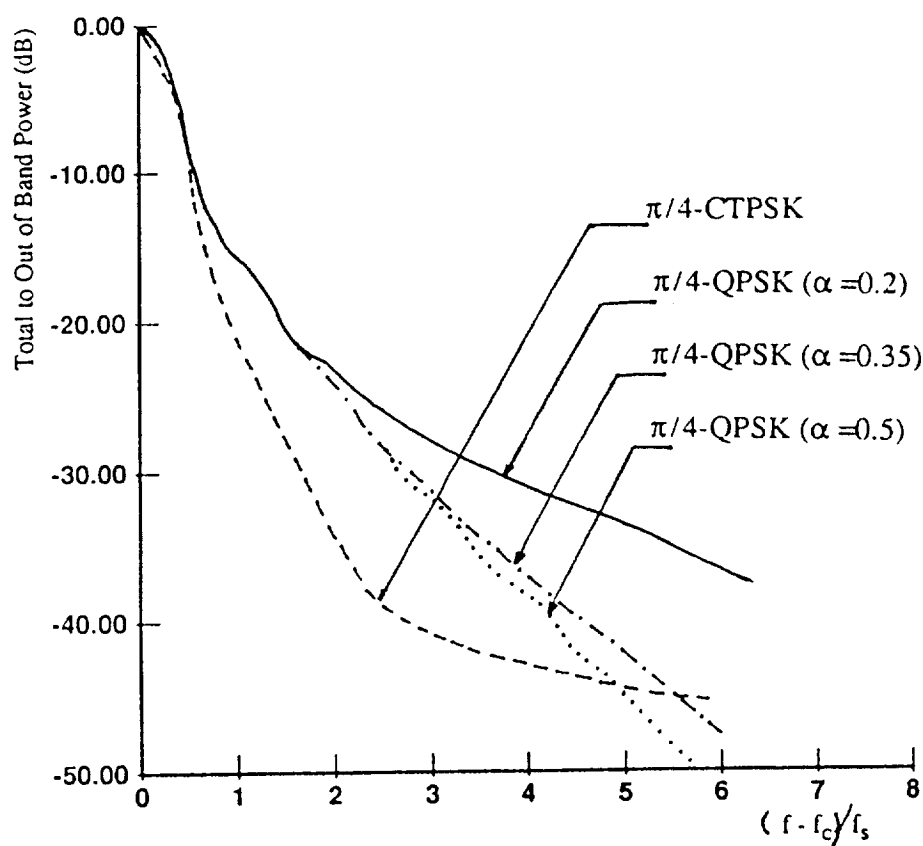
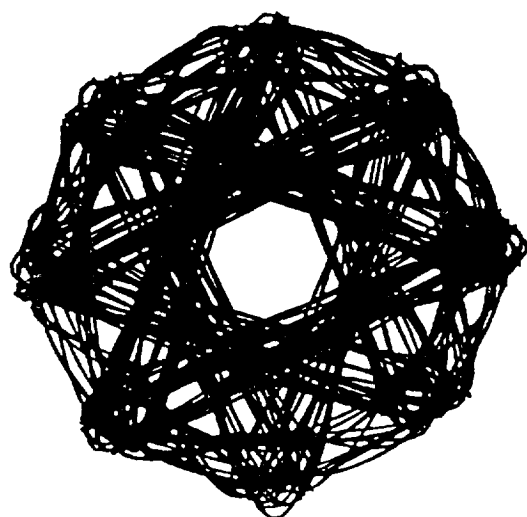
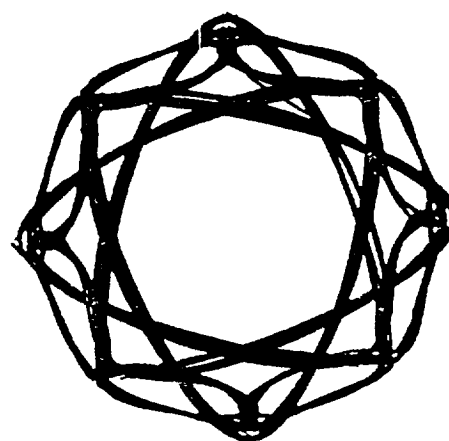


Figure 8. Comparison of total to out of band power ratios of $\pi/4$ -CTPSK and $\pi/4$ -QPSK with $\alpha = 0.2, 0.35$ and 0.5 (Hard-limited channel).



(c) $\pi/4$ -QPSK ($\alpha = 0.5$)



(d) $\pi/4$ -CTPSK

Figure 9. Signal space diagrams (signal trajectories) of $\pi/4$ -QPSK and $\pi/4$ -CTPSK.

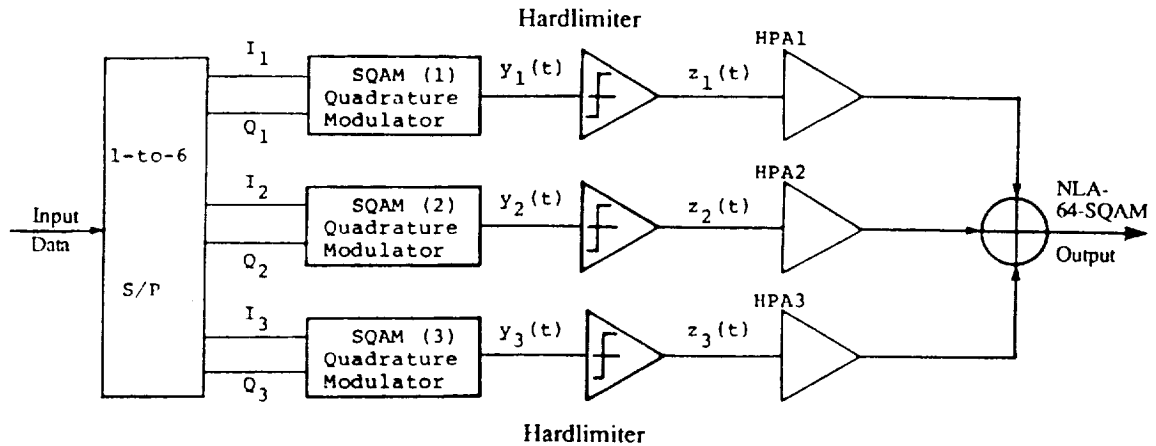


Figure 10. Block diagram of the NLA-64SQAM modulator. HPA1, HPA2 and HPA3 are operated in saturation mode.

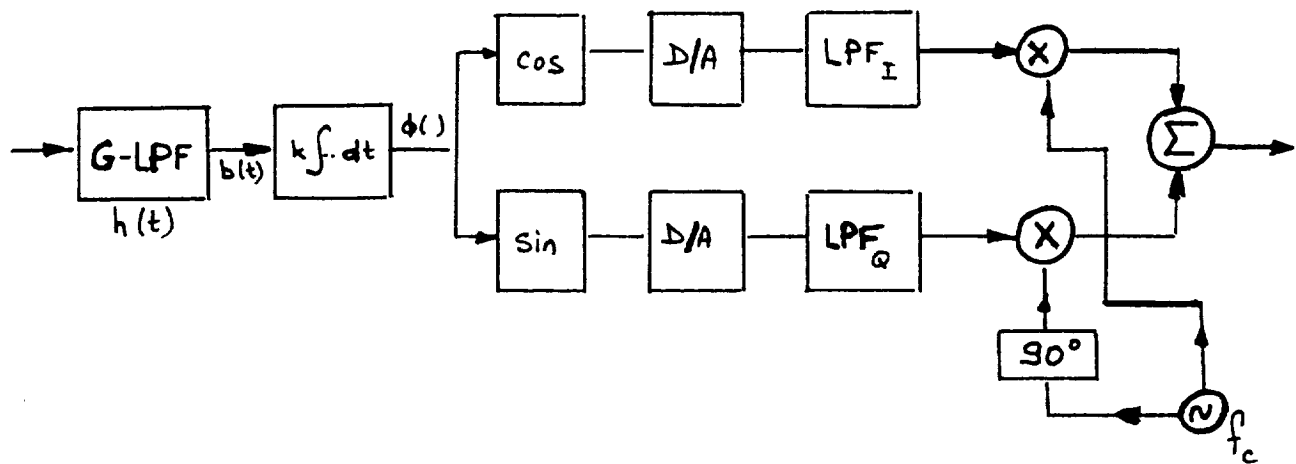


Figure 11. Continuous Phase Modulated (CPM) - Multistate Gaussian MSK G-MSK Block Diagram

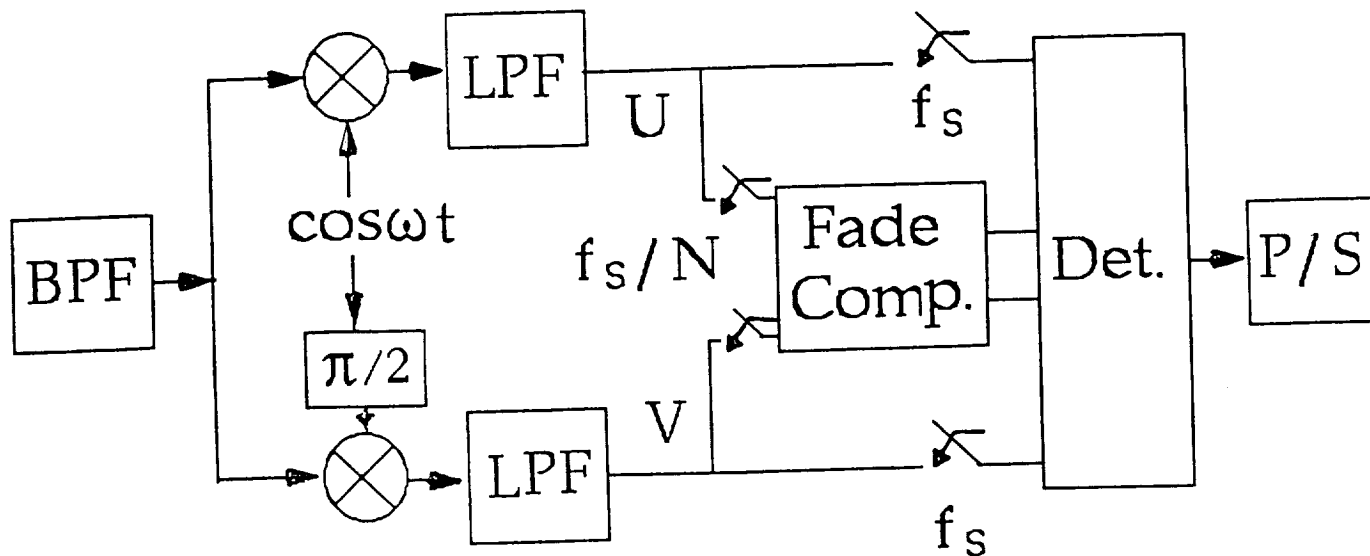


Figure 12. block diagram of the receiver of phase noise and Doppler shift PSK systems. The fade compensation block estimates the random phase caused by the Doppler spread. This random phase is subtracted from the detected phase of the signals in the decision block.

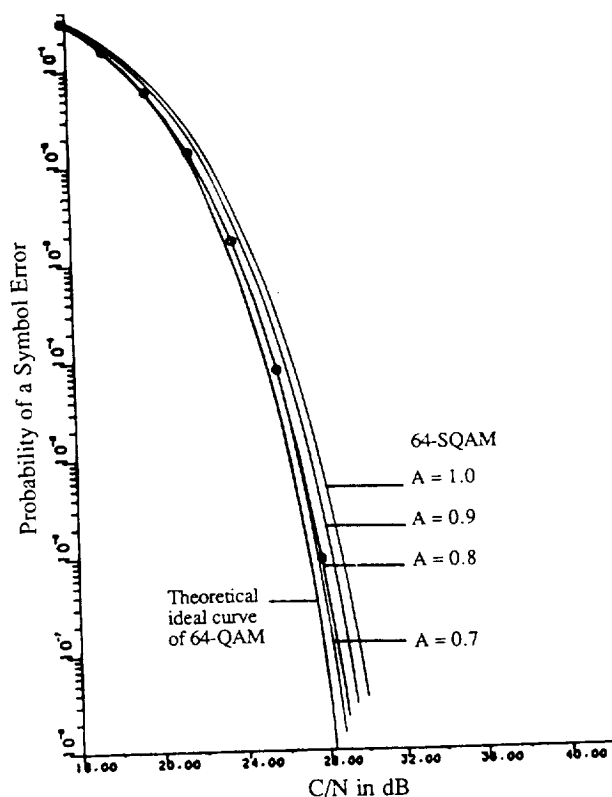


Figure 13. $P(e)$ performance of a 64SQAM modem in an AWGN linear channel. Note: 4th-order Butterworth LPFs are used in the receiver [Ref. 4 and 7].

REFERENCES

1. K. Feher: "Modems for Emerging Digital Cellular Mobile Radio Systems," (invited paper), *IEEE Transactions on Vehicular Technology*, May 1991.
2. H. Katoh, K. Feher: "SP-QPSK: A New Modulation Technique for Satellite and Land-mobile Digital Broadcasting," *IEEE Transactions on Broadcasting*, Vol. 36, September 1990, pp. 195-202.
3. D. Subasinghe-Dias, K. Feher: "Baseband Pulse Shaping Techniques for Improved Spectral Efficiency $\pi/4$ -DQPSK in Non-Linearly Amplified Channels," *Proceedings of the IEEE Vehicular Technology Conference*, VTC-91, St. Louis, MO, May 19-21, 1991.
4. K. Feher, Ed.: Advanced Digital Communications: Systems and Signal Processing Techniques, Prentice-Hall, Inc., Englewood Cliffs, NJ 07632; 1987.
5. J.S. Seo, K. Feher: Superposed Quadrature Modulated Baseband Signal Processor, U.S. Patent No. 4,644,565, issued Feb. 17, 1987. Canadian Patent No. 1-265-851, issued Feb. 13, 1990.
6. K. Feher: "Modulation Techniques for Power and Spectrally Efficient SATCOM Systems," *Proceedings of the Advanced Modulation and Coding Technology Conference*, NASA Lewis Research Center, Cleveland, OH, June 1989.
7. J.S. Seo, K. Feher: "Bandwidth Compressive 64-State SQAM Modems for Nonlinearly Amplified SATCOM Systems," *International Journal of Satellite Communications*, Vol. 9, July 1991.